VLBI-Laser Intercomparison Project

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The VLBI-Laser Intercomparison Project was established at the direction of NASA to assess state-of-the-art geodetic measurement systems being developed by NASA. A Project plan describing the objectives of the Project, the methods for making the assessment, and the schedule, was reviewed. The plan was approved and published. This article describes the contents of the plan.

I. Introduction

A. General

The primary objective of the DSN VLBI-Laser Intercomparison Project is the accurate measurement of baseline vectors, both length and direction, between established geodetic benchmarks.[1]

A second objective is the intercomparison between both satellite and lunar laser ranging techniques with VLBI. Both geodetic and geodynamic measurement instruments are to be evaluated. This is to provide potential users with an assessment of the value of the different instruments. This assessment is to be performed in terms of accuracy of the baselines measured and/or the geodynamic parameters measured, the operability of each instrument and, finally, the cost of operations of each system. This leads to the demonstration of the suitability of the various systems to potential applications.

[1] A surveyor's mark made on a permanent landmark that has a known position altitude that can be used by various geodetic measurement systems.

B. Specific Objectives

The specific objectives of the Project are divided into immediate and future objectives. The immediate objectives are to: assess current VLBI and Laser System performance, identify potential problems in the application of VLBI or Laser Systems by NASA or other agencies, assist system development to overcome problems, and finally, demonstrate readiness for technology transfer. All these objectives are intended to be accomplished by 1979, except for the intercomparison between VLBI and Lunar Laser Ranging (LURE) which is not planned to be accomplished until early 1980.

Beyond 1980 the objectives of the Project are to demonstrate performance of the five-centimeter VLBI system in an operational environment and intercomparison with LURE.

C. Assessment Criteria

The VLBI and Laser Systems will be judged on their ability to measure vectors between benchmarks in terms of relative accuracy, since no absolute scale can be found. By relative accuracy is meant the repeatability of each system's measurements over the measurement session and, in cases where appropriate, the ability to close figures such as triangles.

Secondly, the operability, that is the ability to operate each system, will be assessed. This will be done by noting the differences between planned observations and actually accomplished observations of the measurement's sources during each session.

Finally, the life-cycle cost of each system will also be a basis for judgement. By life-cycle cost is meant the implementation cost of an operational system and the operating cost over the life-cycle of the system. Operational costs will be measured in terms of man-months of effort per month, and shipping and setup costs rather than actual salary dollars to avoid evaluation dependence on salary structure of the user agency or contractor.

D. Accuracy Demonstration

The objective of demonstrating geodetic and geodynamic measurement accuracy can be satisfied by an experiment which will produce necessary and sufficient results. For example, if a more accurate measurement technique existed, then the accuracy of VLBI could be demonstrated by comparison to this more accurate technique. For short baselines where conventional surveys can provide centimeter accuracy, this comparably accurate technique does exist. However, on long baselines there is no demonstrated technique for producing comparable accuracies.

Consequently, in the absence of a more accurate measurement technique, no known test of sufficiency has been found. What can be done is to satisfy an exhaustive set of necessary conditions to infer the accuracy.

II. Error Source Evaluation Methods

The VLBI error sources can be grouped for analysis as follows: First, there are the VLBI subsystems, some of which can be isolated and examined singly. Others must be lumped together for evaluation. Table 1 lists the subsystems, the types of errors that arise, the methods for evaluating each subsystem or group of subsystems, and the measurement session in which the evaluation will occur (see paragraph III for measurement session schedule).

A second set of error sources can be called natural. These are shown in Table 2 and include the structure and position of the radio source, the ionosphere, and the troposphere. In two of these instances, ionosphere and troposphere, related research has been conducted for some years by DSN Advanced Systems. Also, more work is planned in the future to evaluate the water vapor radiometer in an absolute sense. The Project will closely monitor these activities. But, they are not part of this Project plan since they have been or will be carried out regardless of this Project's sponsorship.

It is the intent of the Project to conduct VLBI experiments in certain environmental conditions such as variable humidity to investigate the effect on the interferometry of water vapor, for example.

System evaluations will be conducted as follows: First, short baseline closure and repeatability will be performed to investigate instrument errors. Also, comparisons with conventional surveys, such as NGS will be conducted.

Secondly, contential baseline closure and repeatability can demonstrate VLBI capability and comparisons with satellite laser ranging can be made.

Third, intercontential baseline comparisons with LURE are planned as intercomparison with the VLBI system. The Universal Time 1 and polar motion determined by both systems will also be compared to establish the geodynamic capability of the two systems.

III. Measurement Session Schedule

The Project is organized and conducted as a series of measurement sessions. Each session is designed to achieve specific objectives as developed in later portions of this plan. Sessions are generally conducted once per year. Sufficient time should be allowed between measurement sessions to evaluate the results so that the planning for the next session can take full advantage of the knowledge obtained from the last session.

The measurement sessions evolve from the simple to complex by increasing system sensitivity and performance, by adding more calibrations and by lengthening the baseline being measured. Also, there are sessions which are intended to penetrate deeply into one aspect or subsystem of the system which may also be conducted and which may in fact be simpler measurements but performed under more highly controlled conditions to isolate error sources of the system.

Figure 1 shows the overall VLBI-Laser Intercomparison Project schedule. The top two lines indicate the periods for data acquisition for each measurement session and the schedule for project reports. As shown, each session has a presession plan describing the objectives of the session and a postsession report listing the results.

The planning for each session involves preparation of a pre-session report to document specific objective, measurement strategy and technique, and estimate its estimated accuracies. The pre-session report also identifies the hardware and software required and the schedule for data acquisition, reduction, and analysis. The measurement is then performed.

The post-session report is published to document the results. In the post-session report the experiences learned in terms of operational difficulty and the equipment requirements for the next session should be identified. Most important of all, the accuracy actually obtained will be published.

Also, there is an overall Project plan, which is this document, and there will be a final Project report at the end of the Project.

The next line item on the schedule are flight project events and are included to show periods of peak activity and heavy loading on DSN facilities. As can be seen from the data acquisition measurement section schedule, sessions are for the most part intended to avoid these heavy deep space probe activity periods to facilitate antenna scheduling.

The next three line items show the deployment schedule for the mobile satellite laser ranging equipment (MOBLAS), the Geoceivers, which employ satellite Doppler measurements to determine their position, and the ARIES antenna which provides a mobile arm for the VLBI system. The planned deployments of these three systems require coordination and the agreement of the respective agencies before the plan can be finalized. Specifically, the deployment of the Geoceivers of the National Geodetic Survey in Session Four at Haystack, Goldstone, and Ft. Davis, needs to be agreed upon.

The next six line items, VLBI data acquisition racks, RF phase calibrators, water vapor radiometers, hydrogen masers, noise adding radiometers, and the Caltech-JPL Mark II Correlator are major equipment items that are required for certain sessions as indicated by the cross-hatched bars. Note that the Mark II Correlator will not be employed in Session Six since the DSN VLBI processor subsystem will be used for correlation and estimation for this final session.

The next items are surveys being conducted by the NGS as part of certain intercomparisons mainly, the survey at DSS 14 between the intersection of axes of this antenna, a benchmark or monument beside DSS 14, to the MOBLAS location pad and the ARIES pad 300 meters from the DSS 14 antenna. A second survey which is planned if the intra-complex report indicates that the anticipated accuracies are sufficient to provide a highly precise intercomparison with VLBI will be conducted over the entire Goldstone complex. This survey will primarily be used to compare the DSS 14 to DSS 13 baseline. However, since survey techniques require the establishment of a network of measuring devices the other Goldstone antennas can also be surveyed without a great additional cost. It should be noted that DSS 13 will become a wideband VLBI station before DSS 14 and consequently DSS 13 will be used in certain long baseline tests in place of DSS 14 where 14 is unavailable due to other comments. Consequently, by measuring the 13-14 baseline accurately, these DSSs can be used more or less interchangeably.

The next item is the implementation schedule of the DSN VLBI System which will be employed in Session Six for the operational demonstration. DSN VLBI will produce UT1-polar motion routinely from July 1979. The precise DSN VLBI System (5 cm) will be operational in time for Session Six. The DSS 13 VLBI configuration is the next line item and is planned to be completed by October 1978. At that time 100 MHz of spanned bandwidth at X-band would be available.

Finally, the four participating facilities not within the DSN, namely, the Haystack Observatory, the Owens Valley Radio Observatory, the Ft. Davis Observatory, and the LURE equipment at the McDonald and the Haleakala Observatories, are listed as are their required participation periods as shown by cross-hatched bars.

Table 1. Subsystem error source evaluation

Error sources	Evaluation method	Measurement session
Instrumentation		
Frequency standard[a]		
Phase stability		
Phase calibrator[a]; Phase center variations to intersection of axes; Phase path variations due to antenna distortion or subreflector motion; Off-axis pointing phase effect	Short baselines and connected element interferometry	3
Mechanical		
Variation between intersection of axes and benchmark	Comparison with survey	2
Software	Comparison of independently formulated code, comparison of results with identical input data	2

[a]Evaluation provided by Advanced Systems.

Table 2. Natural error source evaluation

Error source	Evaluation method	Measurement session
Source positions and structure		
Uncertainty source positions	Baseline repeatability	2 & 4
Changing source structure	Baseline closure	2 & 4
Ionosphere[a]	S- vs X-band solution (<1 cm)	
Troposphere		
Dry components[a]	Surface measurements (<1 cm)	
Wet component[a]	WVR (water vapor radiometer) calibration (<2 cm)	
	Measurements in highly variable humidity	

[a]Evaluation provided by Advanced Systems and/or ARIES Project.

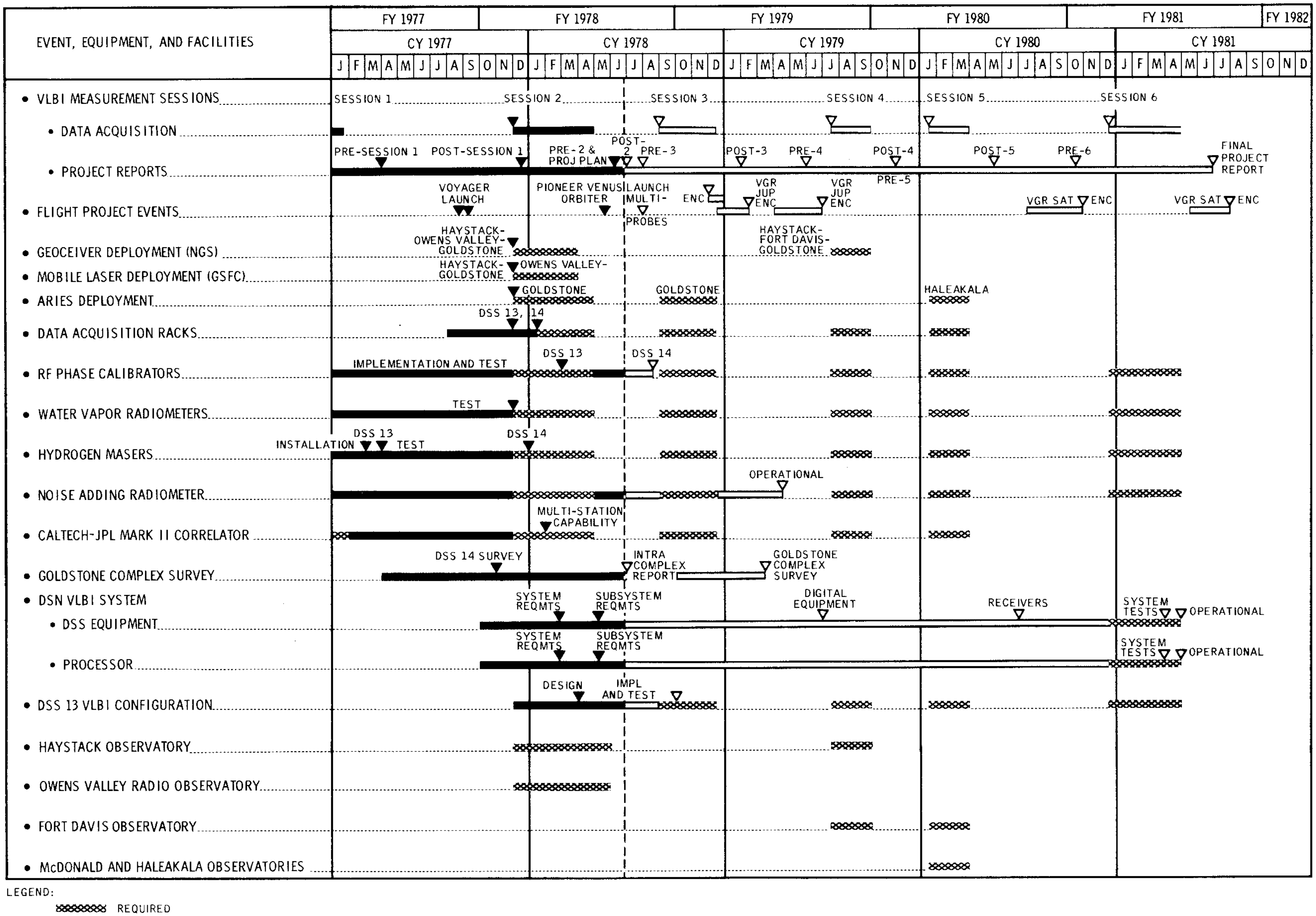

Fig. 1. NASA VLBI-laser intercomparison project schedule